Creation of an Expanded Barell Matrix to Identify Traumatic Brain Injuries of U.S. Military Members

Barbara E. Wojcik, Catherine R. Stein, Jason Orosco,
Karen A. Bagg and Rebecca J. Humphrey

Abstract

This paper describes the creation of a new traumatic brain injury (TBI) classification system, the Barell+ system, derived by the Center for Army Medical Department Strategic Studies. The Barell+ system is an expansion of the standard international Barell body region by nature of injury diagnosis matrix developed by the International Collaborative Effort on Injury Statistics. The expanded version (Barell+) was created as a result of a mapping effort between the original Barell matrix and the Department of Defense severity classification system used for surveillance by the Defense and Veterans Brain Injury Center (DVBIC). Starting with the Barell TBI category definitions, 19 additional TBI-related diagnosis codes from the DVBIC classification were mapped into the resulting Barell+ matrix. The new Barell+ system is compared with the original Barell matrix and the DVBIC classification system. We recommend using the TBI frequency distributions created by the Barell+ system as input data in U.S. military medical modeling and simulation efforts because it better reflects the actual distribution of TBI injuries.

Keywords

injury classification systems, medical resource planning, traumatic brain injury

1. Introduction

Military operations research analysts apply mathematical models to help in the decision-making process of medical planners. These models and simulations assist decision makers in evaluating potential risk and optimizing health-care resource allocation. To provide sound analytical input and support for the U.S. military's medical departments, the quality of data becomes a critical issue. Otherwise, validation of the models developed may not establish the desired level of accuracy between the mathematical model and the real system. It is particularly important to have accurate data for modeling medical systems that require significant allocation of resources and affect the healthcare provided to our military.

In the Department of Defense (DoD), traumatic brain injury (TBI) is a major health issue in both combat and non-combat environments.[1,2] In the U.S. military, during the 10-year period ending in December 2006, the Armed Forces Health Surveillance Center reported that 110,392 service members had at least one TBI-related medical encounter and there were 15,732 hospital admissions with TBI-related diagnoses.[3] The majority of these TBI incidents were the result of falls/miscellaneous and land transport accidents. However, the widespread use of improvised explosive devices (IEDs) in the current conflicts in Afghanistan and Iraq has increased exposure to incidents resulting in TBI to the extent that it has become

Center for AMEDD Strategic Studies, U.S. Army Medical Department
Center & School, USA

Corresponding author:
Dr. Barbara Wojcik
Center for AMEDD Strategic Studies (CASS), 1608 Stanley Road Suite
47, Fort Sam Houston,
TX 78234-5047, USA.
Email: barbara.wojcik@amedd.army.mil

Report Documentation Page		*Form Approved* *OMB No. 0704-0188*

1. REPORT DATE **2010**	2. REPORT TYPE	3. DATES COVERED **00-00-2010 to 00-00-2010**

4. TITLE AND SUBTITLE **Creation of an Expanded Barell Matrix to IdentifyTraumatic Brain Injuries of U.S. Military Members**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **U.S. Army Medical Department Center & School,Center for AMEDD Strategic Studies,Fort Sam Houston,TX,78234-5047**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

This paper describes the creation ofa new traumatic brain injury (TSI) dass ification system, the Barell+ system, derived by the Center for Army Medical Department Strategic Stud ies, The Barell+ system is an expa nsion of the standar.d international Sarell body region by nature of injury diagnosis matrix developed by the Intemational Collaborative Effort on Injury Statistics.The expanded version (Barell+) was created as a result of a mapping effort between the originaiSarell matrix and the Department of Defense severity class ification system used for su rvei lIance by the Defen se an d Veteran Srain Injury Center (DVSIC). Starting with the Barell TSI category definitions, 19 additional TBI-related diagnosis codes from the DVSIC classification were mapped into the resulting Sarell+ matrix. The new Sarell+ system is compared with the original Barel I matrix and the DVSIC dassiflcation system. We recommend using the TBI frequency distributions created by the Sarell+ system as input data in U.s. military medical modeling and simulation efforts because it better reflects the actual di'triburion ofTS I inj u ries.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**10**	

a 'signature wound' of deplo-yed troops in Iraq and Afghanistan.[4-6] One study suggests that 15% of returning soldiers have experienced a concussion,[7] and others estimate that at least 22% of the evacuated wounded have a TBI.[3,8,9]

Recognizing the significant health concern of TBI to the DoD and to assure a coordinated departmental effort, the Assistant Secretary of Defense (Health Affairs) issued a memorandum on the 'Consolidation of Traumatic Brain Injury Initiatives in the Department of Defense' (Health Affairs Memorandum, dated March 23, 2007). Included in the memorandum was the designation of the Defense and Veterans Brain Injury Center (DVBIC) as the single office responsible for the consolidation of all DoD TBI-related incidence and prevalence data collected by the services. A second memorandum established the DoD definition of TBI, the criteria for severity of brain injury stratification, and the method of data collection for monthly reports to DVBIC by the services (Health Affairs Memorandum, dated October 1, 2007). In the memorandum, TBI is defined as a 'traumatically induced structural injury and/or physiological disruption of brain function as a result of an external force that is indicated by new onset or worsening of at least one of the . . . clinical signs, immediately following the event. . . .' The stated clinical signs are (1) 'any period of loss of or a decreased level of consciousness,' (2) 'any loss of memory for events immediately before or after the injury,' (3) 'any alteration in mental state at the time of the injury such as confusion or slowed thinking,' (4) 'neurological deficits such as weakness or change in vision that may or may not be transient,' and (5) 'intracranial lesion.' The definition also states that most signs and symptoms will manifest immediately following the event, but that some may be delayed for days or months. The DoD criterion for brain injury severity stratifies TBI as mild, moderate, severe or penetrating.

The DoD definition established in the October memorandum identifies TBI in a patient/casualty setting. However, there are times when it is necessary to identify and classify TBI cases from medical records. The DVBIC-led DoD TBI Surveillance Working Group reviewed trauma diagnoses from the International Classification of Diseases, 9th Revision, Clinical Modification (ICD-9-CM)[10] and the DoD extender codes for personal history of TBI. The Working Group formed a consensus on which diagnosis codes would be used to identify TBI and what the assigned severity category should be for each diagnosis code. The resulting system classifies TBI into five mutually exclusive severity categories: penetrating, severe, moderate, mild, and unclassified.

There are several other classification systems in existence that categorize TBI, primarily on the basis of severity (i.e. mild/moderate/severe).[11] However, one internationally derived injury classification system resulted in a different type of TBI categorization. The Barell body region by nature

of injury diagnosis matrix (Barell matrix) is a tool providing a standardized approach for retrieving and reporting injury data that ena-bles comparisons across countries and data sources.[12,13] Approved in 2001 by the International Collaborative Effort (ICE) on Injury Statistics and disseminated in the United States by the National Center for Health Statistics (Centers for Disease Control and Prevention),[14] the matrix was the result of a multi-year effort by ICE participants to reach consensus on how to group injury diagnoses. The Barell matrix classifies each ICD-9-CM trauma diagnosis code (800-995) into a unique cell of a two-dimensional array consisting of 12 nature of injury columns (e.g. fracture, open wound) and 36 body-region rows (e.g. hip, upper leg and thigh, knee)[12,14] There are also two predefined groupings of the 36 body regions for more generalized categories into either nine rows (e.g. lower extremities, spinal cord injuries) or five rows (e.g. torso, spine and back). In the full matrix, three rows categorize TBI based on evidence of intracranial injury and length of loss of consciousness (LOC), with the categories called Type 1 TBI, Type 2 TBI and Type 3 TBI.

Since its approval by the ICE on Injury Statistics, the Barell matrix has proved to be useful for categorizing injuries within and between populations.[15-20] In addition, in the past few years, the usefulness of the matrix has been expanded beyond its original construct, and it has proved to be a valuable research tool, enabling more complex injury analyses.[21-24] Using the structure of the Barell matrix, Wojcik et al.[21] were able to compare the injury distributions (based on patient condition codes) used as input to the U.S. Army's Patient Workload Generator (PATGEN) simulation model with injury distributions (based on ICD-9-CM diagnosis codes) from Operation Iraqi Freedom (OIF) data. Recently, Clark and Ahmad[23] illustrated another novel use of the Barell injury matrix when estimating injury severity. The authors were able to assign a probability of survival, Abbreviated Injury Scale (AIS) region, and AIS score to each cell of the Barell matrix, and concluded that it was a feasible tool for determining severity scoring similar to scores derived from the ICDMAP-90 or ICISS software.

The Barell matrix was designed for analysis of injury data and can be populated using single or multiple diagnoses per patient.[12] However, when using a single diagnosis, the important information about the extent of the injury may be lost. Only examination of the entire patient's record containing secondary diagnoses will facilitate the capture of a multiple injury profile. Aharonson-Daniel et al.[24] used the Barell matrix to systematically summarize multiple injury diagnosis data into patient injury profiles that maintain body region and nature of injury information, improve the understanding of casemix, and enable efficient staffing of multidisciplinary trauma teams.

Potential simulation models that may be used by U.S. military medical planners to predict requirements for medical resources should consider data collected on U.S. military

Table 1. CASS description of DVBIC-DoD TBI Surveillance Working Group classification of TBI

TBI is classified into five mutually exclusive categories based primarily on length of loss of consciousness (LOC) and on definitions of DoD-defined extender codes for personal history of TBI.[25,26]

Penetrating	Open intracranial wound, with 0 to >24 hours LOC

Severe	Skull fracture
	  or concussion
	  or other intracranial injury
	  without mention of open intracranial injury and with prolonged (>24 hours) LOC

Moderate	Closed or open skull fracture without intracranial injury with 1–24 hours LOC
	  or closed skull fracture with intracranial injury with 0–24 hours LOC
	  or concussion with 31 minutes to 24 hours LOC
	  or closed intracranial injury without skull fracture with 0–24 hours LOC

Mild	Skull fracture without mention of intracranial injury and with unspecified or brief (<1 hour) LOC
	  or concussion with unspecified/brief (≤30 minutes) LOC
	  or post concussion syndrome
	  or other and unspecified injury to head

Unclassified	Late effect of intracranial injury without mention of skull fracture
	  or injury to optic nerve and pathways
	  or personal history of TBI with unknown severity

Table 2. Barell matrix classification of TBI[12,14]

TBI is classified into three mutually exclusive categories based on evidence of intracranial injury and length of loss of consciousness (LOC)

Type 1 TBI	Recorded evidence of intracranial injury or moderate/prolonged (≥1 hour) LOC or injuries to optic nerve pathways
Type 2 TBI	No recorded evidence of intracranial injury and LOC <1 hour or of unknown duration or unspecified
Type 3 TBI	No recorded evidence of intracranial injury and no LOC

Surveillance Working Group consensus as of February 2010). The DVBIC system classifies TBI into five mutually exclusive severity categories that are based primarily on length of LOC and on the definitions of the DoD-defined extender codes for personal history of TBI.[25,26] A Center for Army Medical Department Strategic Studies (CASS)-derived general description of the categories is presented in Table 1. In contrast, the internationally developed Barell matrix classifies TBI into three mutually exclusive categories on the basis of evidence of intracranial injury and LOC (Table 2).[12,14]

Comparing Tables 1 and 2, it is apparent that there are both similarities and differences in the two systems' classification of TBI. When we examined the assignment of ICD-9-CM diagnosis codes specified by each classification system (Table 3), there was a total of 512 diagnoses identified as TBI. The DVBIC classification omits one diagnosis specified by the Barell matrix, while the Barell system omits 19 diagnoses specified by the DVBIC classification. We decided to expand the standard Barell TBI categories to include the additional 19 diagnoses from the DVBIC classification, renaming Type 1 TBI to Type 1+ TBI and so forth, to differentiate the expanded categories from the standard Barell categories. Starting with the standard Barell TBI definitions (Table 2), we assigned each of the additional diagnoses to one of the 'plus' categories. In addition

personnel diagnosed with TBI. Proper data acquisition (identification, specification, and collection) is one of the most challenging steps in simulation methodology. Lack of data quality and verification may limit the practical application of the model and its usefulness for medical planners. This paper proposes an extended version (Barell+) of the international Barell matrix. This version enhances the standard Barell TBI categories with additional ICD-9-CM diagnoses identified by the DVBIC-DoD TBI surveillance classification system. The authors also present a precise mapping between the DVBIC and enhanced Barell TBI classifications that enables standardized, easy comparisons of TBI in DoD personnel with that in other populations.

2. Development of the Expanded Barell Classification

Details on the DVBIC classification system were obtained from the TBI Surveillance Working Group and consisted of a listing of all identified ICD-9-CM TBI diagnosis codes and the corresponding severity categories (based on the

Table 3. Distribution of ICD-9-CM diagnosis codes* in DVBIC and Barell TBI categories

DVBIC	Frequency	%	Barell	Frequency	%
Penetrating	211	41.3	Type 1 TBI	447	90.7
Severe	73	14.3	Type 2 TBI	38	7.7
Moderate	177	34.6	Type 3 TBI	8	1.6
Mild	43	8.4			
Unclassified	7	1.4			
Total	511		Total	493	

*The codes for DoD-specific TBI diagnoses were respecified (by the DoD Unified Biostatistical Utility Working Group), but the diagnoses were only counted once.

Table 4. Barell+ TBI classification system

TBI is classified into four mutually exclusive categories based on evidence of intracranial injury and length of loss of consciousness (LOC)

Type 1+ TBI	Recorded evidence of intracranial injury or moderate/prolonged (≥1 hour) LOC or injuries to optic nerve pathways	All Barell Type 1 diagnoses plus 907.0, and V15.5,V15.52,V15.59 (_3,_4,_5,_8,_9,_A,_D,_E,_F)
Type 2+ TBI	No recorded evidence of intracranial injury and LOC <1 hour or of unknown duration or unspecified	All Barell Type 2 diagnoses plus V15.5,V15.52,V15.59 (_2,_7,_C)
Type 3+ TBI	No recorded evidence of intracranial injury and no LOC	All Barell Type 3 diagnoses plus 310.2, 959.01[a]
Unknown Type	No information on intracranial injury and unknown level of LOC	3-digit 850, V15.5,V15.52,V15.59 (_1,_6,_B) for personal history of TBI with unknown level of severity

[a]Note that 959.01 is in the Other Head row of the standard Barell matrix.

to the assigned DVBIC diagnoses, each of the modified categories contains the diagnoses from the standard system. As a result, Barell+ classifies TBI into four mutually exclusive types: Type 1+ TBI, Type 2+ TBI, Type 3+ TBI, and Unknown Type (Table 4).

Fifteen of the 19 codes added to the Barell classification are ICD-9-CM V codes specifically developed for the DoD and mandatory when coding traumatic brain injuries of injured military personnel. The V codes capture the personal TBI history, which includes details on the Global War on Terror (GWOT) status as well as the nature and severity of the injury. The other diagnosis codes added to the Barell+ classification include 310.2, 'postconcussion syndrome'; the 3-digit code 850, 'concussion'; 907.0, 'late effects of intracranial injury without mention of skull fracture'; and 959.01, 'head injury unspecified.' Note that code 959.01 is included in the 'Other Head' row of the standard Barell matrix, and if an analyst is using the programming code available from the U.S. Centers for Disease Control and Prevention (CDC)[14] for assigning Barell row and column values as a basis for programming the expanded matrix, the analyst would need to adjust the program to avoid assignment of this diagnosis to two cells of the expanded matrix. Note that only the Barell taxonomy includes shaken infant syndrome, code 995.55, which understandably is not included in the DVBIC taxonomy that is aimed at military personnel. Also note that both the DVBIC and Barell+ classifications are based on 5-digit ICD-9-CM diagnosis codes, although there are a few exceptions.

3. Comparisons of Defense and Veterans Brain Injury Center and Barell+ Classifications

Figure 1 illustrates how individual TBI-related ICD-9-CM diagnosis codes assign into different categories within the two taxonomies. For example, all codes 800.3x map into the Barell+ category of Type 1+ TBI; however, the same

codes are divided into moderate and severe within the DVBIC taxonomy. Included in the illustration is the application of a business rule used in both the DVBIC and Barell+ systems to handle short or incomplete diagnosis codes that may occur in real-world data. As an example, code 800.1 would be assigned to the same category as 800.10, or in other words, it is assumed that incomplete diagnosis codes are missing trailing zeros. To further highlight the difference and similarities between the two systems, we examined the categories of each system in terms of the other system (based on the total number of unique diagnosis codes in the cross-mapping) (Figures 2 and 3). For example, in Figure 2 it is clear that the DVBIC Penetrating and Severe categories are entirely composed of Barell+ Type 1+ TBI; while in contrast (Figure 3), Barell+ Type 1+ TBI contains primarily Penetrating and Severe diagnoses, but also some Moderate and Unclassified diagnoses. As a final illustration contrasting the DVBIC and Barell+ TBI classifications, Figure 4 presents the mapping or cross tabulation between the DVBIC and Barell+ taxonomies. Note that this representation of the cross tabulation includes specific notation of the mapping of incomplete diagnosis codes (e.g. 851.0 and 851.00 are both specified).

4. Comparisons of Barell and Barell+ Classifications

The expanded Barell matrix is designed to parallel the Barell matrix by providing a tool to organize injury diagnosis data into meaningful groups by body region and nature of injury. The expanded Barell was developed to be as similar to the standard Barell matrix as possible, acknowledging the differences in coding systems. Differences between the Barell matrix and the expanded Barell are primarily due to differences between the level of detail typically found in DoD ICD-9-CM codes. We examined TBI profiles generated by the original and expanded Barell matrices for both

Figure 1 content (DVBIC / Dx / Barell+):

DVBIC	Dx	Barell+
Mild	800.0, 800.00	Type 2 + TBI
	800.01	Type 3 + TBI
	800.02	Type 2 + TBI
Moderate	800.03	Type 1 + TBI
Severe	800.04, 800.05	
Mild	800.06, 800.09	Type 2 + TBI
Moderate	800.1, 800.10, 800.11, 800.12, 800.13	Type 1 + TBI
Severe	800.14, 800.15	
Moderate	800.16, 800.19	
Moderate	800.2, 800.20, 800.21, 800.22, 800.23	Type 1 + TBI
Severe	800.24, 800.25	
Moderate	800.26, 800.29	
Moderate	800.3, 800.30, 800.31, 800.32, 800.33	Type 1 + TBI
Severe	800.34, 800.35	
Moderate	800.36, 800.39	
Moderate	800.4, 800.40, 800.41, 800.42, 800.43	Type 1 + TBI
Severe	800.44, 800.45	
Moderate	800.46, 800.49	
Mild	800.5, 800.50	Type 2 + TBI
	800.51	Type 3 + TBI
	800.52	Type 2 + TBI
Moderate	800.53	Type 1 + TBI
Severe	800.54, 800.55	
Moderate	800.56, 800.59	Type 2 + TBI
Penetrating	800.6, 800.60, 800.61, 800.62, 800.63, 800.64, 800.65, 800.66, 800.69	Type 1 + TBI
Penetrating	800.7, 800.70, 800.71, 800.72, 800.73, 800.74, 800.75, 800.76, 800.79	Type 1 + TBI
Penetrating	800.8, 800.80, 800.81, 800.82, 800.83, 800.84, 800.85, 800.86, 800.89	Type 1 + TBI
Penetrating	800.9, 800.90, 800.91, 800.92, 800.93, 800.94, 800.95, 800.96, 800.99	Type 1 + TBI

Figure 1. DVBIC and Barell+ category assignment of ICD-9-CM 800.xx (fracture of vault of skull)

Figure 2 content:

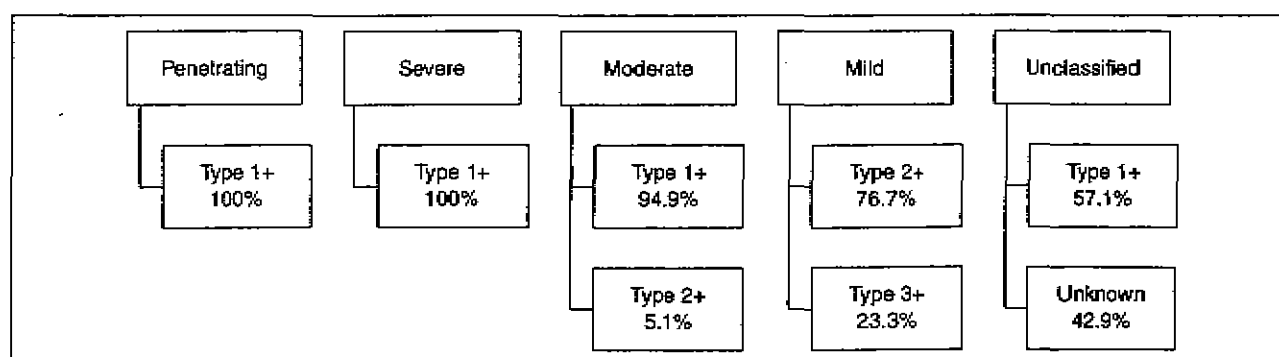| Penetrating	Severe	Moderate	Mild	Unclassified
Type 1+ 100%	Type 1+ 100%	Type 1+ 94.9%	Type 2+ 76.7%	Type 1+ 57.1%
		Type 2+ 5.1%	Type 3+ 23.3%	Unknown 42.9%

Figure 2. Distribution of Barell+ categories within each DVBIC category (based on 511 ICD-9-CM diagnosis codes)
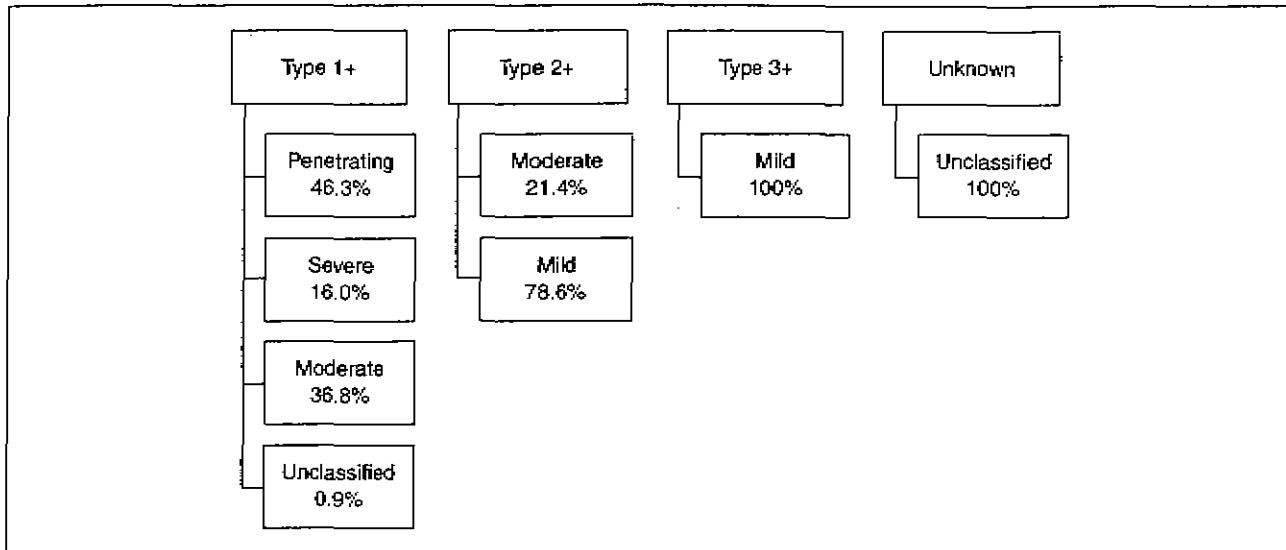
Figure 3. Distribution of DVBIC categories within each Barell+ category (based on 511 ICD-9-CM diagnosis codes)

in-theater and post-deployment phases. For each scenario, we found significant differences in TBI distributions.

Using a sample of diagnosis codes from admission data, the expanded-Barell matrix yielded 12,469 records of TBI, 29% more TBI-related admissions than using the standard Barell matrix. Descriptive analysis revealed that TBI was identified in the Type 3 TBI category far more than other TBI groups (Table 5). A chi-square test was used in testing the null hypothesis that both TBI systems create similar (homogeneous) distributions with respect to the proportion of TBI cases falling into each TBI category (Type 1, Type 2, Type 3, and Unknown).

The test statistic for assessing homogeneity is

$$\chi^2 = \sum_{i=1}^{r}\sum_{j=1}^{c} \frac{(n_{ij} - E_{ij})^2}{E_{ij}}$$

where

$$E_{ij} = \frac{n_i n_j}{N}$$

and E_{ij} is the estimated expected value for the ijth cell, n_{ij} is the count in the ijth cell, n_i is the row total for the brain injury severity category i of the row variable, and n_j is the corresponding term for the jth Barell classification category of the column variable.

Patients with TBI were significantly more likely ($p < 0.0001$) to be diagnosed under the Barell+ classification system (see the footnote in Table 5) at $\alpha = 0.05$. This indicates that there is statistical significance in the difference between the profiles of brain injury identified under the Barell classification system as compared to the Barell+ matrix. Therefore, if the user wants to identify TBI among

the population at risk, he/she should incorporate the expanded Barell classification system to maximize the selection of TBI-related injuries.

5. Discussion and Conclusions

During the past years of OIF and Operation Enduring Freedom (OEF), a significant number of the severe closed and penetrating TBI U.S. military patients were diagnosed and treated in military treatment facilities. These service members were presented for care during deployment, although many of the chronic cases were continued or diagnosed after the military members came back from the theater. The RAND Corporation released a report estimating that 20% of the 1.6 million U.S. service members (approximately 300,000) may have a mild TBI, and most of the cases may go untreated.[27]

Any modeling or simulation project that includes future force requirement planning and provides decision support for the determination of wartime medical capabilities (e.g. the Medical and Casualty Estimation Model (MACE), the Joint Medical Analysis Tool (JMAT)) has to take into consideration the quality of the input data, including TBI probability distributions. Future models will need to provide data-driven estimates regarding hospital workload requirements, patient workload, usage, evacuation requirements, etc. If the input TBI profiles are not representative of TBI distributions observed in recent conflicts, models based on non-representative data might result in erroneous model output. Consequently, the U.S. military model might underestimate patient workload and the severity of TBI cases. To overcome the problem, this study compared an

| DVBIC | Barell+ | | | |
	TBI Type 1+	TBI Type 2+	TBI Type 3+	Unknown Type
Penetrating	800, 801, 803, 804 (.6–.9),			
	851 (.1, .3, .5, .7, .9),			
	852 (.1, .3, .5),			
	853, 854 (.1),			
	V15 .5, V15.52, V15.59 (_5, _A, _F)			
Severe	800, 801, 803, 804 (.04, .05, .14, .15, .24, .25, .34, .35, .44, .45, .54, .55),			
	850 (.3, .4),			
	851 (.04, .05, .24, .25, .44, .45, .64, .65, .84, .85),			
	852 (.04, .05, .24, .25, .44, .45),			
	853, 854 (.04, .05),			
	V15 .5, V15.52, V15.59 (_4, _9, _E)			
Moderate	800, 801, 803, 804 (.03, .1, .10–.16, .19, .2, .20–.26, .29, .3, .30–.36, .39, .4, .40–.46, .49, .53),	800, 801, 803, 804 (.56, .59),		
	850.2,	850.12		
	851 (.0, .00–.06, .09, .2, .20–.23, .26, .29, .4, .40–.43, .46, .49, .6, .60–.63, .66, .69, .8, .80–.83, .86, .89),			
	852 (.0, .00–.03, .06, .09, .2, .20–.23, .26, .29, .4, .40–.43, .46, .49),			
	853, 854 (.0, .00–.03, .06, .09),			
	V15 .5, V15.52, V15.59 (_3, _8, _D)			
Mild		800, 801, 803, 804 (.0, .00, .02, .06, .09, .5, .50, .52),	310.2,	
		850 (., .0, .1, .11, .5, .9),	800, 801, 803, 804 (.01, .51),	
		V15 .5, V15.52, V15.59 (_2, _7, _C)	959.01	
Unclassified	907.0,			V15 .5, V15.52, V15.59 (_1, _6, _B)
	950 (.1–.3),			
	995.55			

Figure 4. Map of categorization of TBI diagnosis codes between DVBIC and Barell+ classifications

Table 5. Frequency and percentage (chi-square test) to assess the relation between TBI category and the TBI diagnoses identified and classified by the standard and expanded Barell TBI classifications.

TBI category	Standard Barell	Expanded Barell	$2 \chi^2(df)$	P
Type 1	3,749 (38.8%)	3,927 (31.5%)		
Type 2	5,877 (60.9%)	6,145 (49.3%)		
Type 3	26 (0.3%)	2,044 (16.4%)		
Unknown	0 (0.0%)	353 (2.8%)		
Total	9,652	12,469	2004.18	[a]<0.0001

[a]Significant difference ($p < 0.05$). All percentages are column percentages.

international civilian classification system known as the Barell matrix with the DoD-established DVBIC TBI surveillance classification.

Current TBI classification systems have limitations that preclude the accurate assessment of the TBI population within the U.S. military. The Barell matrix is based on the presence or absence of intracranial injury and level of consciousness. Furthermore, Type 1 TBI, the most severe, also includes shaken infant syndrome and injuries to the optic nerve. While in contrast, in the DVBIC system, injuries to the optic nerve fall into the unclassified TBI category and the shaken infant syndrome is not included. Therefore, one cannot compare and contrast the military TBI population to other TBI populations using the current TBI classification systems.

The major contribution of this paper was to establish a precise mapping strategy between the DVBIC (DoD official) TBI classification system and the standard Barell matrix. As a result of our work, the expan-ded Barell+ was created. Our analysis showed a significant difference in TBI profiles between the two systems, Barell and Barell+. Significant results of the chi-square test indicated the substantial shift in the TBI profiles produced by both systems. The expanded version (Barell+) would correct an underestimation of the category of mild TBIs and an overestimation of the group of penetrating TBIs when compared to the original Barell matrix. Moreover, an additional category, 'Unknown Type,' was added in order to account for personal history of TBI with unknown level of severity. As a result, operations research analysts may be more accurate in their modeling efforts when the TBI profiles created by the Barell+ system are utilized.

In addition, the Barell+ classification, being based on the Barell matrix, can classify multiple injury diagnoses per patient. Consequently, multiple injury profiles can be identified from the Barell+ system using body region, nature of injury, or cross classification of the two. This application of the Barell+ classification is important, since multiple injuries are associated with greater severity, worse outcomes,

and usually require treatment by a multidisciplinary team of physicians.[24] In a study conducted by Halpin et al.,[28] the inclusion of multiple injuries not only led to a substantial increase in the total number of injuries treated, but also to an increase in diagnosis-specific and body region-specific injury rates. Therefore, multiple injury profiles resulting from using the Barell+ system could provide better data for determining staffing or supply requirements.

Because the consequence of using the traditional Barell matrix to identify U.S. military personnel with TBI symptoms will result in underestimation of Type 3 TBI, we recommend using the expanded Barell matrix (Barell+) over the standard Barell matrix to provide TBI distributions in future U.S. military modeling and simulation projects. Because the Barell+ enables multiple injury profiles, we also recommend it over the DVBIC classification for providing TBI distributions in military medical modeling and simulation.

6. References

1. Sutton LK. From the Director. *DCoE in Action* 2009; 2(2): 2 (available at www.dcoe.health.mil)
2. Centers for Disease Control and Prevention (CDC). *Facts about Traumatic Brain Injury*, www.cdc.gov/ncipc/tbi/Factsheets/Facts_About_TBI.pdf (2006, accessed May 2009).
3. Army Medical Surveillance Activity. Traumatic brain injury among members of active components, U.S. Armed Forces, 1997-2006. *Med Surveillance Mon Rep* 2007; 14(5): 2–6.
4. Martin EM, Lu WC, Helmick K, et al. Traumatic brain injuries sustained in the Afghanistan and Iraq wars. *Am J Nurs* 2008; 108(4): 40–47.
5. Galarneau MR, Woodruff SI, Dye JL, et al. Traumatic brain injury during Operation Iraqi Freedom: findings from the United States Navy–Marine Corps Combat Trauma Registry. *J Neurosurg* 2008; 108: 950–957.
6. Department of Defense Task Force on Mental Health. *An achievable vision: report of the Department of Defense Task Force on Mental Health*. Falls Church, VA: Defense Health Board. http://www.ha.osd.mil/dhb/mhtf/MHTF-Report-Final.pdf (2007, accessed 15 December 2009).
7. Hoge CW, McGurk D, Thomas JL, et al. Mild traumatic brain injury in U.S. Soldiers returning from Iraq. *N Engl J Med* 2008; 358(5): 453–463.
8. Warden DL. Military TBI during the Iraq and Afghanistan Wars. *J Head Trauma Rehabil* 2006; 21(5): 398–402.
9. Okie S. Traumatic brain injury in the war zone. *N Engl J Med* 2005; 352(20): 2043–2047.
10. Practice Management Information Corporation. *International Classification of Diseases, 9th Revision, Clinical Modification (ICD-9-CM)*, 6th edn. Los Angeles, CA: PMIC, 2007.
11. Langlois JA, Rutland-Brown W, and Thomas KE. *Traumatic brain injury in the United States: emergency department visits, hospitalizations, and deaths*. Atlanta, GA: Centers for

Disease Control and Prevention, National Center for Injury Prevention and Control, 2006.

12. Barell V, Aharonson-Daniel L, Fingerhut LA, et al. An introduction to the Barell body region by nature of injury diagnosis matrix. *Inj Prev* 2002; 8(2): 91–96.

13. Fingerhut LA. International collaborative effort on injury statistics: 10 year review. *Inj Prev* 2004; 10(5): 264–267.

14. National Center for Health Statistics and International Collaborative Effort(ICE)onInjuryStatistics.*TheBarellInjury Diagnosis Matrix, classification by body region and nature of the injury*. Hyattsville, MD: Centers for Disease Control and Prevention, National Center for Health Statistics. http://www.cdc.gov/nchs/injury/ice/barellmatrix.htm (last modified 13 October 2009, accessed 3 November 2009).

15. Owens PL, Zodet MW, Berdahl T, et al. Annual report on health care for children and youth in the United States: focus on injury-related emergency department utilization and expenditures. *Ambul Pediatr* 2008; 8(4): 219–240.

16. Nannini A, Lazar J, Berg C, et al. Physical injuries reported on hospital visits for assault during the pregnancy-associated period. *Nurs Res* 2008; 57(3): 144–149.

17. Santamarina-Rubio E, Perez K, Ricart I, et al. Injury profiles of road traffic deaths. *Accid Anal Prev* 2007; 39(1): 1–5.

18. Greenspan AI, Coronado VG, Mackenzie EJ, et al. Injury hospitalizations: using the nationwide inpatient sample. *J Trauma Inf Infect Crit Care* 2006; 61(5): 1234–1243.

19. Petridou E, Kedikoglou S, Belechri M, et al. The mosaic of equestrian-related injuries in Greece. *J Trauma-Inj Infect Crit Care* 2004; 56(3): 643–647.

20. Aharonson-Daniel L, Waisman Y, Dannon Y, et al. Epidemiology of terror-related versus non-terror-related traumatic injury in children. *Pediatrics* 2003; 112(4): 280–284.

21. Wojcik BE, Humphrey RJ, Fulton LV, et al. Comparison of Operation Iraqi Freedom and Patient Workload Generator injury distributions. *Mil Med* 2008; 173(7): 647–652.

22. Farchi S, Camilloni L, Giorgi Rossi P, et al. Agreement between emergency room and discharge diagnoses in a population of injured inpatients: determinants and mortality. *J Trauma-Inj Infect Crit Care* 2007; 62(5): 1207–1214.

23. Clark DE, Ahmad S. Estimating injury severity using the Barell matrix. *Inj Prev* 2006; 12(2): 111–116.

24. Aharonson-Daniel L, Boyko V, Ziv A, et al. A new approach to the analysis of multiple injuries using data from a national trauma registry. *Inj Prev* 2003; 9(2): 156–162.

25. Unified Biostatistical Utility. *Military health system coding guidance: professional services and specialty coding guidelines, version 3.2*. Department of Defense, 2009.

26. Unified Biostatistical Utility. *Military health system coding guidance: professional services and specialty coding guidelines, version 3.2*. Department of Defense, 2008.

27. Tanielian, T, Jaycox, LH (eds). *Invisible wounds of war: psychological and cognitive injuries, their consequences, and services to assist recovery*. Santa Monica, CA: RAND, 2008.

28. Halpin J, Greenspan AI, Haileyesus T, and Annest JL. The effect of counting principal and secondary injuries on national estimates of motor vehicle-related trauma: a NEISS-AIP special study. *Inj Prev* 2009; 15(5): 328–333.

Acknowledgement

Author Biographies

Dr Barbara Wojcik, Senior Scientist and Chief, Statistical Analysis Branch, Center for AMEDD Strategic Studies, Fort Sam Houston, Texas, is a recognized expert in military medical research, statistics, epidemiology, health care surveillance, computer science, and data mining. She holds a PhD in Statistics from the Polish Academy of Sciences, and a MS in Electronic Engineering from the Warsaw Technical University. Her latest articles concern mental disorders and TBI hospitalizations surveillance of U.S. Army soldiers deployed to Iraq and Afghanistan, disease and non-battle injury admission model and rate estimates, and multiple injury analyses. Dr. Wojcik has taught statistics and research methods at several institutions: the U.S. Army-Baylor University Graduate Program in Healthcare Administration; Webster University, Fort Sam Houston; University of Texas at San Antonio; and Wichita State University, Kansas. In 1997, Dr. Wojcik was recognized by the American Cancer Society as one of the 25 best cancer researchers. Her scientific work was featured in articles by the New York Times in February 2000 and the magazine Self in 2002.

Catherine Stein is a health statistician at the U.S. Army's CASS, Fort Sam Houston, Texas. She is a graduate of the Stephen F. Austin State University (BSF and MS in Forestry) and the University of Texas in San Antonio (MS in Statistics), and was formerly an entomologist with the U.S. Forest Service. In 1996, she was co-editor of a special issue of the Journal of Ambulatory Care Management, 'Technology in Emergency Care.' Her most recent projects at CASS have dealt with aspects of traumatic brain injury surveillance.

Jason Orosco is a health statistician at the U.S. Army's CASS, Fort Sam Houston, Texas. He is a graduate of the University of Incarnate Word (BS in Mathematics) and a student of Texas A&M University (MS in Statistics). Prior to working for CASS, he has spent the past nine years working for Fortune 500 companies, such as Blockbuster and

FedEx, providing analytical solutions to business opportunities. In Jan 2010, he was co-author of a publication on traumatic brain injury hospitalizations of U.S. Army Soldiers deployed to Afghanistan and Iraq. His latest work at CASS has dealt with the surveillance of mental health disorders among soldiers deployed to Iraq and Afghanistan.

Karen Bagg is a health statistician at the U.S. Army's CASS. She is a graduate of Trinity University (BA in Mathematics and Sociology) and the University of Texas at San Antonio (MS is in Statistics). Ms. Bagg is also a former U.S. Army aviator and operations research analyst. Her recent publications concern the surveillance of traumatic brain injury hospitalizations and the health effects of temperature and light on deployed soldiers.

Rebecca Humphrey is a health statistician at the U.S. Army's CASS. She is a graduate of the University of Wisconsin-Eau Claire (BS in Psychology) and Baylor University (MA in Behavioral Statistics). Ms. Humphrey also serves as a Military Health System subject matter expert, substantially adding to the success of CASS projects. Her recent work has included the disease and non-battle injury admission model and rates determination, rehabilitative and convalescent care analysis, and traumatic brain injury hospitalization surveillance.